2013

Why They Leave: Understanding Student Attrition from Engineering Majors

Brandi N. Geisinger
Iowa State University, brandige@iastate.edu

D. Raj Raman
Iowa State University, rajraman@iastate.edu

International Journal of Engineering Education Vol. 29, No. 4, pp. 914–925, 2013
Printed in Great Britain

0949-149X/91 $3.00+0.00

Why They Leave: Understanding Student Attrition from Engineering Majors*

BRANDI N. GEISINGER and D. RAJ RAMAN
Research Institute for Studies in Education, Iowa State University, Ames, IA 50011, USA. E-mail: brandige@iastate.edu

A large number of students leave engineering majors prior to graduation despite efforts to increase retention rates. To improve retention rates in engineering programs, the reasons why students leave engineering must be determined. In this paper, we review the literature on attrition from engineering programs to identify the breadth of factors that contribute to students' decisions to leave. Fifty studies on student attrition from engineering programs were included in the primary part of this literature review. In the second half of the work, an additional twenty-five studies that focused on methods of increasing student retention, were examined. Six broad factors driving students to leave engineering were identified by examining the attrition literature: classroom and academic climate, grades and conceptual understanding, self-efficacy and self-confidence, high school preparation, interest and career goals, and race and gender. Evidence from the retention studies suggests that successful efforts to increase retention act on one or more of these factors. A clear gap in the literature is that of economics: the costs associated with losing students, and the costs associated with implementing retention strategies, are virtually unmentioned.

Keywords: engineering education; STEM education; attrition, retention

1. Introduction

Researchers have been studying the low retention and graduation rates in U.S. engineering programs for over half a century [1], often citing evidence suggesting that too few students are graduating with engineering degrees to meet an ever increasing need for qualified engineering professionals [2]. Well trained engineers are a critical human resource for modern technological civilization, but a lack of engineers is not only a problem for highly industrialized nations: engineers are desperately needed in many developing countries since about 20% of the world's population lives without clean water, 40% lacks adequate sanitation, and 20% is homeless [3–4]. One estimate suggests that over 2.5 million engineers are needed in Africa alone to ensure that basic human needs are met [4], and these needs are only expected to increase in coming years [3].

The number of engineering students completing their degrees in engineering depends on two factors, the first being enrollment rate, which is a function of multiple factors, including recruitment efforts and tuition costs, and the second being year-to-year retention rate, which is a measure of the number of students staying in engineering from year-to-year through the curriculum. Like enrollment rate, retention rate is related to a multitude of factors. Engineering graduation rate is a measure of the proportion of students completing an engineering degree program compared with the number of students that have entered the program. Mathematically, graduation rates can be approximated as the product of year-to-year retention rates. Over the last 60 years, U.S. engineering graduation rates have consistently hovered around 50% [1, 5–11], suggesting that nearly half of the students entering engineering degree programs in the U.S. leave prior to graduation.

There is little debate regarding the wastefulness resulting from the high attrition rate of engineering students from engineering degree programs. Despite the plethora of studies on retention of engineering students, it has been well over a decade since the publication of the last comprehensive review summarizing why students leave engineering [2]. Froyd and Ohland's literature review focused primarily on integrated curriculums, not on the reasons why students leave engineering, and Daempfle's non-peer-reviewed report relies primarily on literature from the 1980s and 1990s [12–13]. Also, while there is a steady flow of funding for new research on the retention of engineering students, and of scholarly work in this area, a concise summary of what has been learned, and which practices are most likely to increase retention, is absent in the literature. Understanding both the efficacy and economics of various retention strategies is central to developing rational policies to improve engineering retention rates. To this end, we have attempted here to summarize the results from peer reviewed publications examining the retention of engineering students over the last five decades. We have further attempted to categorize these studies based upon a variety of factors (e.g., sample size, type of institution), and we conclude by suggesting evidence-based strategies for increasing retention, and recommending potential avenues for further research.

* Accepted 13 March 2013.

2. Scope/method

To examine the issue of why students leave engineering degree programs, and how to increase retention rates, we conducted a review of the literature on issues related to student attrition and retention in the field of engineering. To locate relevant materials, search strings such as "students leaving engineering," "engineering attrition," and "engineering retention," were entered into the Thomson Reuters Web of Knowledge, the Education Resources Information Center (ERIC), and Google Scholar. Studies that did not meet the relevance (i.e., focused on issues of attrition and retention) criteria, or that did not make clear conclusions (e.g., meeting papers that described plans for a study without specific conclusions) were not included. This process yielded fifty relevant, rigorous studies related to the reasons why students leave engineering, and these were used as the basis for this review—the total number of studies was not predetermined. To enable a comparison between the problems identified as driving low retention to the approaches used to increase retention, we sought out additional reports of retention enhancement, using a literature search and selection criteria parallel to that described above. This effort identified an additional twenty-five studies related to improving student retention rates. Most of these twenty-five studies examined engineering students in particular, but studies pertaining to STEM students and students overall were also included since there are relatively few studies that examine efforts to improve overall retention rates in engineering programs.

To facilitate analysis and presentation the fifty attrition studies were categorized by type and scope, and then similar factors were grouped into broad categories to begin the identification of specific factors that influence attrition. Key information about each attrition study was organized into Table 1 to summarize the results of the literature search. Specifically, Table 1 lists, for all fifty studies, the total number of participants, the type of data collected, the type of institution at which data were collected, participant major, and whether the study focused on underrepresented minority students or women. The sample size and type of data collected were included since they reveal basic information about the scope and type of study conducted. Five studies [6, 11, 14–16] included multiple types of data with differing numbers of participants for the two methodologies. In these cases, the participant numbers are combined and the types of data are listed. The type of institution at which the study was conducted was also noted, since different institutions may attract students from different backgrounds and vary in their ability to recruit and retain students [17–19]. For any study that named the institution where the study took place, the classification of the institution by the Carnegie Foundation for the Advancement of Teaching was provided [20]. Most of the studies included in the attrition analysis focused on engineering majors. However, some of the studies included majors from other science, technology, and mathematics (STEM) related disciplines. Because it is possible that engineering majors differ in some respects from other, albeit related, disciplines [21] participant major included in each study is also noted.

3. Results

3.1 Scope of the reviewed literature

As shown in Table 1, study sizes and types varied widely. Participant numbers ranged from five to over 90 000, with a mean of approximately 9700 and median of 640; the large difference between mean and median reflects the skewed distribution of participants, with six studies having over 15 000 participants. Twenty-seven of the fifty studies included longitudinal data, which in this context meant they collected historical academic information such as high school and college transcript information, high school class rank, high school and college grade point averages, SAT scores, ACT scores, major persistence, and/or college drop-out information. Twenty-five of the fifty studies included survey data; eleven relied on interview data. One study of the fifty included classroom observation data, one relied on ethnographic data, one included focus group data, and one used experimental data (which involved female engineering students' response to experiencing stereotype threat). Thirty-three of the fifty studies included in Table 1 were published after Seymour and Hewitt's review on student attrition from STEM programs [2].

Of the studies with known classification, ten took place at public institutions with very high research activity, one took place at a public institution with high research activity, one was at a public associate's institution, and one was at a private baccalaureate institution. Four of the research papers stated that the data were collected at a "Research University" but did not list the institution name—in these cases they are marked as "Research University." Fourteen studies took place at an "unknown" institution type, meaning that the authors did not list enough information about the institution at which the study took place to be able classify the institution. Fourteen studies included data from multiple institutions, and four of the studies used national databases. The majority of total partici-

Table 1. Surveyed Literature on STEM Student Attrition, ordered by year published

	n	Data type	Institution type*	Major	Focus on women or underrepresented minority students?
Steinberg (1949)	NA	Discussion	NA	Engineering	
Augustine (1966)	397	Interview & Survey	3 Universities	Engineering	
Ott (1978)	4591	Longitudinal & Survey	16 Universities	Engineering	
Deboer (1984)	216	Survey	Unknown	Science	
Felder & Silverman (1988)	NA	Literature Review	NA	Engineering	
McDade (1988)	409	Interview &Longitudinal	Unknown	Chemistry and Mathematics	
Levin & Wyckoff (1990)	1043	Longitudinal	Public Research University (VH)	Engineering	
Humphreys & Friedland (1992)	1232	Longitudinal	Public Research University (VH)	Engineering	
Seymour (1992)	330	Interview	Unknown	SEM	
Sondgeroth & Stough (1992)	38	Interview & Survey	Unknown	Engineering	Minorities
Strenta et al. (1994)	5320	Longitudinal & Survey	4 Universities	SM	
Felder et al. (1995)	121	Longitudinal & Survey	Public Research University (VH)	Engineering	Women
Woolston et al. (1995)	392	Survey	Public Research University (VH) & Public Teaching University	Engineering	
Besterfield-Sacre et al. (1997)	417	Survey	Public Research University (VH)	Engineering	
Moller-Wong & Eide (1997)	1151	Longitudinal	Public Research University (VH)	Engineering	
Schaefers et al. (1997)	278	Longitudinal & Survey	Unknown	Engineering	
Seymour & Hewitt (1997)	335	Interview	Unknown	SEM	
Adelman (1998)	14835	Longitudinal & Survey	National Data	Engineering	
Brainard & Carlin (1998)	672	Longitudinal & Survey	Public Research University (VH)	SE	Women
Grandy (1998)	6290	Longitudinal & Survey	Multiple Universities	SEM	Minorities
Nauta et al. (1999)	255	Survey	Unknown	Engineering	Women
Baillie & Fitzgerald (2000)	50	Interview & Survey	Public Associate's Rural-Serving Large	Engineering	
Huang et al. (2000)	24599	Longitudinal & Survey	National Data	SE	Women & Minorities
Daempfle (2002)	NA	Literature Review	NA	SEM	
Good et al. (2002)	12	Interview	Unknown	Engineering	Minorities
Bell et al. (2003)	48	Experimental	Public Research University (VH)	Engineering	Women
Lent et al. (2003)	328	Survey	Unknown	Engineering	
Leuwerke et al. (2004)	844	Longitudinal & Survey	Unknown	Engineering	
Ohland et al. (2004)	Unknown	Longitudinal	9 Universities	Engineering	
Zhang et al. (2004)	87167	Longitudinal	9 Universities	Engineering	
French et al. (2005)	Unknown	Longitudinal & Survey	Unknown	Engineering	
Fleming et al. (2006)	5	Interview	Unknown	Engineering	
Suresh (2006)	604	Interview, Longitudinal, & Survey	Research University	Engineering	
Bernold et al. (2007)	1022	Longitudinal & Survey	Public Research University (VH)	Engineering	
Haag et al. (2007)	Unknown	Survey	Public Research University (VH)	Engineering	
Johnson (2007)	16	Interview & Observation	Research University	Science	Minority Women
Marra et al. (2007)	120	Survey	5 Universities	Engineering	
Tyson et al. (2007)	91148	Longitudinal	Multiple Universities	STEM	
Rask & Tiefenthaler (2008)	10622	Longitudinal	Private, Baccalaureate Arts & Sciences	Economics	Women
Stevens et al. (2008)	Unknown	Ethnography	4 Universities	Engineering	
Vogt (2008)	713	Longitudinal & Survey	4 Research Universities	Engineering	
Chen & Thomas (2009)	12000	Longitudinal	National Data	STEM	
Lagoudas (2009)	6	Interview	Research University	Engineering	Women
Marra et al. (2009)	113	Survey	Unknown	Engineering	
Kokkelenberg & Sinha (2010)	44000	Longitudinal	Public Research University (H)	STEM	
Ohland et al. (2011)	75000	Longitudinal	9 Universities	Engineering	Women & Minorities
Griffith (2010)	Unknown	Longitudinal	National Data	STEM	Women & Minorities
Ost (2010)	17145	Longitudinal	Research University	Sciences	
Wee et al. (2010)	1393	Focus Group & Survey	Unknown	Engineering	Women
Tyson (2011)	1027	Longitudinal	Multiple Universities	Engineering	

* According to the Carnegie Foundation for the Advancement of Teaching (2012). (H) Indicates high research activity while (VH) indicates very high research activity.

pants came from studies involving multiple universities (67%), with an additional 13% of total participants coming from national data, and 12% from students at public research institutions. Other categories of institution accounted for the remaining 8% of the total participant count.

Thirty-four of the fifty studies focused solely on engineering majors, ten included both engineering students and students from other STEM areas, and five studies focused on non-engineering majors from allied disciplines. Although most of the studies discussed, to some extent, how gender and race might influence retention, some of the studies had an explicit focus on the experiences of women and/or racial and ethnic minorities in engineering programs. For each study with a special focus on these areas, the specific population focus is noted in Table 1. Ten of the fifty studies focused on the experiences of women, six focused on the experiences of minorities, and one focused on minority women.

3.2 Explaining student attrition

While some faculty members consider high attrition rates from engineering programs to be an unavoidable consequence of convincing under-prepared or unmotivated students to leave engineering degree programs—a process sometimes referred to as "weeding out"—most authors working in this area are concerned about high attrition rates, citing evidence suggesting that the students who leave engineering are often doing well academically [2, 7, 22] and that women and minorities leave science and engineering majors at disproportionately high rates [11, 17, 23]. These findings suggest that students leave engineering for reasons far beyond simple preparedness and motivation.

The literature cited in Table 1 attempts to examine why students leave engineering programs. When considering this body of literature as a whole, it is possible to identify a common set of factors that contribute to poor retention rates in engineering programs. These factors include: the unwelcoming academic climate found in many engineering programs, conceptual difficulties with core courses, a lack of self-efficacy or self-confidence, inadequate high school preparation, insufficient interest-in or commitment-to the field of engineering or a change in career goals, and racism and/or sexism. Below, each of these factors is discussed in greater detail and supporting evidence is examined. Table 2 summarizes the results and evidence for each of the attrition factors.

3.2.1 Classroom and academic climate

Just over half (27) of the fifty studies identified the classroom and academic climate as a factor in students' decisions to leave engineering programs. The majority of these 27 studies relied on survey or interview data since the large longitudinal studies did not have a means of assessing students' experi-

Table 2. Summary of results

Factors related to attrition	Number of studies providing evidence*
Classroom and academic climate	27
Inadequate teaching and advising	14
Lack of faculty guidance, encouragement, support, and attention	8
Competitive or hostile environment	3
Inadequate teaching style	4
Individualistic culture	11
Lack of sense of engagement or belonging	3
Sense of isolation	3
Grades and conceptual understanding	23
Conceptual difficulties	8
Low course grades drive students away (regardless of conceptual understanding)	11
Self-efficacy and self-confidence	15
High school preparation	28
Inadequate mathematics preparation	4
Inadequate science, physics, and chemistry preparation	4
Inadequate overall high school GPA	3
Inadequate high school class rank	3
ACT/SAT scores	6
Interest and career goals	17
Race and gender	26
Sexism	4

* The number of studies in the subsections does not add up to the total number of studies in each section since some studies may have provided evidence for multiple subjections. Conversely, other studies were unrelated to the subsections listed and fit only with the broader section. No major themes, or subsections, were found for sections on self-efficacy and self-confidence or interest and career goals.

ences. These 27 studies suggested two distinct issues, namely 1) inadequate teaching and advising and 2) the individualistic culture found in engineering programs that focuses on competition rather than cooperation, as detailed below.

3.2.1.1 Classroom and academic climate—teaching and advising

Inadequate teaching and advising was a commonly cited reason why students leave science and engineering majors [2, 8, 13, 22, 24–31]. Specifically, researchers noted the lack of faculty guidance and academic support [2, 25, 30–32], the lack of personal encouragement and attention from faculty members [2, 26–27, 30, 32], the competitive environment fostered in science and engineering classrooms [30], and mismatches between the way engineering is taught and the way students learn [24, 33]. Sondgeroth and Stough [29] found that students who persisted in engineering, as well as those who left, cited poor teaching as an obstacle to their success and described the culture as "hostile." Further, Cabrera et al. [34] found that teaching styles were more important in predicting student success in the classroom than was the students' amount of precollege preparation, a finding that suggests that engineering instructors can play a crucial role in increasing retention

Owing to the ways in which women and racial and ethnic minorities are differentially socialized to respond to competition and encouragement [35], some of the factors related to the structure of teaching and advising in science and engineering classrooms have been found to be more harmful to women and minorities than to their white male counterparts [2, 26, 30]. Seymour and Hewitt [2], for example, noted that classroom competition was more harmful to female students than it was to male students.

3.2.1.2 Classroom and academic climate—individualistic culture

Another reason that students provide for leaving engineering degree programs is the individualistic nature of engineering classrooms and the engineering profession. Multiple authors have found science and engineering students report feeling a lack of engagement with their communities and other engineering students [25], a lack of a sense of belonging [22, 28], a lack of personal identification with the field of engineering [36], and an overall sense of isolation [8, 32, 37]. In fact, Marra [22] reported that the lack of a sense of belonging in the engineering program was the most important factor in a student's decision to leave engineering. For this reason, extroverts have been shown to have higher rates of attrition from engineering programs than their introverted peers [38]. Further, Augustine [6] found that compared with students who persist in engineering, students who leave engineering majors attach higher importance to working with other people. Similarly, Suresh [15] found that students were more likely to persist if they perceived a culture of support in their program, Grandy [39] found that students were more likely to persist if they had better support systems, and Seymour and Hewitt [2] found that the individualistic focus was especially harmful to minority students, who often felt obligations to help others, serve their communities, and be role models.

3.2.2 Grades and conceptual understanding

Just under half (23) of the studies indicated that grades and conceptual understanding played a role in students' decisions to leave engineering programs. Somewhat in keeping with the "weed out" model of engineering education, many studies indicated that students who left science and engineering majors were experiencing conceptual difficulties with their courses [2, 8, 22, 25, 28, 31, 37, 40]. However, whether these conceptual difficulties reflected a prior capability (or lack thereof) of students to conceive how mathematics maps to the physical world, or whether they reflected the instructional challenges of making these linkages for students, was not fully explored in the literature.

Many studies indicated that low college grades, which are intended to serve as a measure of conceptual understanding, predict student attrition from engineering [5, 6, 11, 40–42], and that physics, chemistry and calculus grades are particularly good predictors [43]. Other studies indicated, however, that the low grades themselves—and not a lack of understanding of course material—may serve to drive students to other disciplines with less stringent grading policies [15]. Many students who left reported that they were accustomed to being at the top of their classes and their grades were not meeting their expectations [6, 37], or that they were unhappy with their grades [28], or that their grades were unequal to the amount of work required to attain them [8, 27], or that they were experiencing discouragement and loss of self-esteem due to their low grades [2, 8]. Fleming et al. [25] reported that some students experienced financial difficulties when they lost scholarships due to lower-than-expected GPAs. Rask and Tiefenthaler [44] and Ost [45] suggested that the effects of low grades on major persistence may be stronger for women, perhaps due to women's higher expectations for themselves [46], or to stereotype threat [27, 45, 47].

Interestingly, while a number of studies have shown that college GPA can predict student attrition from science and engineering [5, 11, 40, 42, 48], others have shown that students who leave these programs have a wide range of GPAs and that the GPAs of students who leave are not meaningfully different from those of the students who graduate with science and engineering degrees [2, 22, 49]. In fact, ten of the fifty studies suggested that students who leave engineering programs do not experience greater conceptual difficulties than do those students who stay. Besterfield-Sacre et al. [7] found that students who leave engineering are generally doing well academically. A study by Ohland et al. [50] suggested that a student's decision to leave is often unrelated to their ability to succeed in the engineering curriculum, and Strenta et al. [30] and Seymour and Hewitt [2] provided evidence that students who leave science and engineering do not experience more conceptual difficulties with their courses than the students who stay.

The reason for contradictory results regarding the relationship between GPA and conceptual understanding to student attrition remains uncertain, though many factors—such as student grade level, institution type, student demographics or characteristics, and the time of GPA computation—could explain these differences. Longitudinal studies, which used grades as a measure of conceptual understanding, often relied on the measure of grades alone. While these grades provide some measure of conceptual understanding, low grades could also reflect other problem areas such as lack of interest in the field [19, 51]. The survey and interview studies that assessed conceptual understanding using student self-report ran the risk that respondents could lie, but these studies were better able to differentiate low grades and conceptual understanding of course material.

3.2.3 Self-efficacy and self-confidence

Fifteen of the fifty studies identified students' self-efficacy and self-confidence levels to be related to their decisions to leave engineering majors; three of these studies determined this using interview data and the remaining twelve used survey data. Some research suggested that students who have low levels of self-confidence [8, 21] or self-efficacy [42, 52] are less likely to persist in science and engineering than students with higher levels of self-confidence and self-efficacy because the former are more likely to become discouraged by the competitive grading structure and individualistic climate of engineering classrooms. Vogt [53] also found that when faculty members were accessible to students, students reported higher levels of self-efficacy and higher GPAs, again suggesting a crucial role for engineering instructors. Similarly, studies have shown that students who attribute their failures to themselves rather than to an outside source (such as a faculty member or a difficult test) are less likely to persist in engineering because their self-efficacy is reduced with every perceived failure [54–55]. In a relatively large survey, Wee et al. [16] found that female engineering students have lower levels of self-efficacy and self-confidence than do their male peers, suggesting that these factors could play a role in influencing women's high attrition rates.

3.2.4 High school preparation

Over half (28) of the fifty studies identified high school preparation as a factor in students' decisions to leave (though another four of the studies suggested that high school preparation was not an important factor). These studies used multiple types of data (longitudinal, survey and interview) to reach this conclusion. Some studies noted that having adequate mathematics preparation in high school is important and can predict attrition or retention [1, 10, 39]. Others argued that taking (and earning high grades in) science classes [39], physics [43, 56], social sciences [56], chemistry [43] and calculus [43] are significant in predicting retention in engineering programs. Still others pointed to the predictive value of overall high school GPA [15, 57–58] and high school class rank [5, 41, 56]. Finally, some found ACT scores [5] and SAT scores [15, 58], particularly ACT math scores [42, 56] and SAT math scores [15, 41, 58], to be predictive of student retention. Interestingly, Besterfield-Sacre et al. [7] found that low high school class rank predicts attrition from engineering programs, while very high class rank also predicted attrition, purportedly because if these students became disinterested they were more likely to leave. Evidence suggested that women and racial minorities may have less high school preparation than their majority counterparts and that this could play a role in their higher attrition rates [23].

3.2.5 Interest and career goals

All colleges and majors experience some student attrition due to lack of interest, and the field of engineering is no exception [8, 40, 42]. Seventeen of the fifty studies, which relied on interview and survey data, suggested that student interest factored into their decision to leave. In fact, Grandy [39] found that student interest in the field was more important in predicting student retention than were grades. Further, students leaving engineering reported that other majors were more interesting [2, 8] or that they found a more appealing career option outside of science and engineering [2]. Some students reported rejecting the demanding, solitary lifestyle that that they perceived to be associated with a career in science or engineering [2]. Further evidence suggested that students have only vague ideas about what an engineer does prior to entering college and that these ideas often remain vague upon arrival; this leads some students to leave due to lack of interest or uncertain career goals [28].

3.2.6 Race and gender

Twenty-six of the fifty studies reported that race and/or gender factored into students' decision to leave, and this was discovered by studies relying on interview, survey, and longitudinal data. In most literature, women and minorities have been shown to underperform and leave engineering at higher rates than their white male counterparts [11, 23, 49, 56, 59], even when they have the same or higher levels of pre-college preparation [14, 46]. Women have been shown to leave engineering at higher rates than men even when they perform as well or better in their classes [2, 33]. A few studies suggested that female engineering students actually graduate at the same or higher rates than male engineering students [9, 42]. The reason for these contradictory findings is difficult to discern, but since departmental and engineering college culture varies from place to place, it seems entirely possible that some engineering colleges may—through the culture or through explicit programming—be meeting the needs of women better than other engineering colleges, and that the differences in the literature reflect the different locations at which the work was performed. The frequency with which race and gender are cited as relevant to retention is fairly constant throughout the time-course of the literature reviewed, but future research could shed light on this issue by exploring the link between engineering college, departmental climates toward women, and the retention rates of female undergraduate students.

While factors such as academic climate and low grades can have indirect impacts on the retention of women, some studies suggested that more overt sexism may also affect the retention rates of female engineering students [11, 27, 46, 60]. Good et al. [60], Lagoudas [27], and McDade [11] indicated that female students reported receiving sexist treatment from male faculty members and their male peers who were likely to make assumptions about their (lack of) abilities due to their gender. Similarly, Felder et al. [46] found that female students reported hearing faculty members make sexist comments, and interviewees in a study by Good et al. [60] reported hearing their classmates make sexist jokes. Felder et al. [46] also indicated that group projects could be harmful to women because they were likely to report being undervalued by the men in the group. Finally, Felder et al. [46] reported that the lack of female mentors and role models may negatively influence female engineering students. These last five findings appear to have the potential to motivate specific best practices to improve retention rates (e.g., sensitivity training for faculty and male students, creating teams of women instead of spreading a small number of women across multiple teams in large class, hiring and retaining more women faculty members), and in the next section we focus on the retention literature.

3.3 Improving retention rates

As evidenced by the twenty-five studies identified as related to improving student retention, a broad array of actions can be taken to address student attrition from engineering programs. As shown in Table 3, many of the actions that have been shown to improve retention rates also have been shown to have effects on the factors identified as being related to the reasons why students leave engineering programs. In fact, most of these potential actions have manifold impacts—that is, they address more than one of the attrition factors (learning communities, for example, have been shown to improve the climate, grades and conceptual understanding, self-efficacy and self-confidence, interest levels, program diversity, and overall retention rates [12, 19, 61]). The actions listed in the left column of Table 3 improved retention rates. The studies cited in the "evidence of success" column provide evidence suggesting that the actions listed increase retention rates and address the attrition factors marked. Each action listed addressed one or more of the attrition factors, and Table 3 indicates which attrition factors are addressed by each of the retention-increasing actions. Table 3 thus illustrates the multi-dimensional nature of retention improvement efforts, and also validates our selection of key retention factors.

4. Discussion

As any experienced engineering educator knows, some engineering students leave because they discover a passion for a discipline other than engineering—it is hard to argue that we should be trying to prevent such students from leaving. However, it is also true that a significant proportion of engineering students leave because the engineering educational system has failed to show them that the engineering endeavor is profoundly human, has failed to make relevant the key scientific, mathematical, and engineering principles needed for mastery of engineering, has failed to show that engineering is within reach of their abilities, has failed to capture their imagination and fascination, and has failed to provide a welcoming atmosphere to them. These failures have multiple costs: when qualified engineering students leave their majors prior to graduation, there are expenses at the individual, institutional, and societal levels. Carnevale et al.

Table 3. Potential avenues for increasing retention and attrition factors addressed

	Potential attrition factors addressed						
Potential actions	**Classroom and academic climate**	**Grades and conceptual understanding**	**Self-efficacy and self-confidence**	**High school preparation**	**Interest and career goals**	**Race and gender**	**Evidence of success**
Curricular avenues							
First year seminar	×	×	×		×		[19, 63]
Collaborative or cooperative learning (group projects)	×	×	×		×		[19, 34, 38, 64–68]
Service learning/Projects of social importance	×	×	×				[19, 38, 64, 69–70]
Clearer expectations of diversity and reducing racism and sexism	×					×	[19, 68]
Change courses from lecture formats to laboratory formats			×		×		[60, 71–72]
Integrated curriculum courses			×				[12, 73]
Hands-on design projects			×				[16, 65]
Co-curricular avenues							
Learning communities	×	×	×		×	×	[12, 19, 61]
Student-faculty interaction	×	×	×			×	[19, 34, 53, 61, 74]
Tutoring	×	×	×				[61, 75, 76]
Summer bridge programs	×	×		×	×		[19]
Undergraduate research programs	×	×			×	×	[19, 77]
Study groups	×		×			×	[61]
Supplemental Instruction/ Group tutorial sessions	×	×					[19, 60, 78]
Internships					×		[6, 16]
Extra-curricular avenues							
Student organizations and athletics	×		×		×	×	[16, 19]
Living in residence halls	×		×		×		[19]
Support groups or networks	×	×	×			×	[61, 74, 79]
Attributional retraining (to build self-confidence)			×				[19, 80]
Developmental studies and remedial programs				×			[19]
Personal counseling		×	×				[19, 79, 81]

[62] reported that the difference in median incomes between engineering degree holders and holders of the highest-paid non-STEM field (business) is $15 000 per year. Assuming a 30-year working life, leaving engineering might cost an individual student on the order of one half-million dollars over the course of his or her career. Tuition losses to engineering degree programs are smaller on a per-student basis, but are often larger when considering the total number of students at a large college of engineering: even at a large Midwestern land-grant, tuition on the order of $15 000 per year is commonplace, and loss of students after the freshmen year multiplies the tuition loss by a factor of three, assuming that they graduate in four years. With many engineering schools having incoming classes on the order of 500 to 1000 students, the loss of students may imply tuition losses on the order of millions of dollars per year. Costs to society are much harder to assess, but even if those costs are ignored, it appears that retaining students has high economic value to multiple sectors of society.

The literature on the reasons why students leave engineering majors reveals widely varying sample sizes, methodologies, types of institutions, and populations examined. These studies identified a common set of factors that play a role in students' decisions to leave engineering majors: the culture in engineering programs tends to be individualistic and often involves very traditional types of teaching and advising, students may have difficulties understanding course material and competitive grading structures leave students feeling discouraged, students may lack self-efficacy or self-confidence, students may not have obtained adequate high school preparation, engineering and course material may fail to capture student interest, and students may encounter additional obstacles due to gender, race, or ethnicity. However, researchers have also demonstrated a variety of policies that engineering schools can adopt to increase engineering retention in general, and of women and minorities in particular. These policies are not necessarily without cost, and a critical gap in the literature is systematic documentation of the costs of different retention strategies. A research priority should be determining the cost of various strategies to enhance retention. Combining knowledge of retention-strategy cost with good estimates of the economic benefits to retention would allow cost-benefit analyses on various strategies, which would be extremely useful to institutional leaders and faculty as they work to increase retention. Optimal strategies will clearly depend on institutional resources, but might also depend on the institution type. Although this work examined literature covering multiple institution types, the data did not allow a robust analysis to allow insight into how different strategies map to different institution types.

The factors related to students' decisions to leave are almost certainly interrelated. For instance, a poor classroom climate with inadequate teaching and advising likely leads to students experiencing greater conceptual difficulties and earning lower grades; these conceptual difficulties and low grades probably serve to reduce students' self-efficacy levels. (More perniciously, poor instruction in core courses leaves students with low foundational knowledge that is critical for upper division courses, and a vicious cycle is entered.) On the other hand, students who lack adequate high school preparation are also likely to experience conceptual difficulties and low grades, and therefore they are also likely to suffer from lowered self-efficacy levels. Future research clarifying these relationships could be valuable, as it might be able to shed light on how best to develop a virtuous cycle of student learning and retention in engineering degree programs. However, the complex, cultural, relationship-centric nature of engineering education (and all education for that matter) can mean diminishing returns for pursuing highly mechanistic insight into the process. This paper has identified multiple proven methods of increasing the retention of all students, including women and underrepresented minorities. What is lacking in the engineering-education ecosystem are the incentive structures necessary for deans, department-heads, and individual faculty to implement these methods, especially in light of the multiple and sometimes conflicting incentives for other activities at many universities. The cost–benefit analyses suggested above should be combined with studies that examine how best to incentivize faculty and university leaders to implement policies that are known to work.

5. Conclusions

This review of the literature identified six broad factors driving students to leave engineering: classroom and academic climate, grades and conceptual understanding, self-efficacy and self-confidence, high school preparation, interest and career goals, and race and gender. Furthermore, published retention studies suggest that retention can be increased by addressing one or more of these six factors. The review identified a clear gap in the literature, namely the costs associated with losing students, and the costs associated with implementing retention strategies. A better understanding of these costs might encourage academic units to focus more strongly on retention, and might also provide useful guidance to educators and administrators on the most cost-effective approaches to increasing retention.

Acknowledgements—The authors would like to express their sincere thanks to Amy Kaleita, Mari Kemis and Andrew Ryder for constructive comments on a draft version of this work. Although not funded directly by any external agency, this project grew out of a collaboration nucleated by the National Science Foundation under Award No. EEC-0813570. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

1. S. S. Steinberg, The relations of secondary mathematics to engineering education, *Mathematics teacher,* **42**(8), 1949.
2. E. Seymour and N. Hewitt, *Talking About Leaving*, Westview Press, Boulder, CO, 1997.
3. B. Amadei, Engineering for the developing world, National Academy of Engineering, http://engineeringchallenges.org, 2011.
4. C. Ottery, Lack of engineers stifling development, says report, Science and Development Network, http://www.scidev.net, 2010.
5. C. Adelman, Women and men of the engineering path: A model for the analysis of undergraduate careers, U.S. Department of Education, Washington, DC, 1998.
6. R. D. Augustine, Persistence and attrition of engineering students: A study of freshman and sophomore engineering

students at three Midwestern universities, U.S. Department of Health, Education, and Welfare, Office of Education, 1966.
7. M. Besterfield-Sacre, C. J. Atman and L. J. Shuman, Characteristics of freshman engineering students: Models for determining student attrition in engineering, *Journal of Engineering Education,* **86**(2), 1997, pp. 139–149.
8. S. G. Brainard and L. Carlin, A six-year longitudinal study of undergraduate women in engineering and science, *Journal of Engineering Education,* **87**(4), 1998, pp. 369–375.
9. G. Huang, N. Taddese, E. Walter and S. S. Peng, Entry and persistence of women and minorities in college science and engineering education, National Center for Education Statistics, U.S. Department of Education Office of Educational Research and Improvement, 2000.
10. E. C. Kokkelenberg and E. Sinha, Who succeeds in STEM studies? An analysis of Binghamton University undergraduate students, *Economics of Education Review,* **29**, 2010, pp. 935–946.
11. L. McDade, Knowing the "right stuff": Gender, attrition, and scientific literacy, *Anthropology and Education Quarterly,* **19**(2), 1988, pp. 93–114.
12. J. E. Froyd and M. Ohland, Integrated engineering curricula, *Journal of Engineering Education,* **94**(1), 2005, pp. 147–164.
13. P. A. Daempfle, An analysis of the high attrition rates among first year college science, math, and engineering majors, U.S. Department of Education, Office of Educational Research and Improvement, 2002.
14. M. D. Ott, Retention of men and women engineering students, *Research in Higher Education,* **9**(2), 1978, pp. 137–150.
15. R. Suresh, The relationship between barrier courses and persistence in engineering, *Journal of College Student Retention,* **8**(2), 2006, pp. 215–239.
16. S. Wee, R. M. Cordova-Wentling, R. F. Korte, S. M. Larson and M. C. Loui, Why many smart women leave engineering: A preliminary study of how engineering students form career goals, *Proceedings of the 40th ASEE/IEEE Frontiers in Education Conference,* Washington, DC, 2010.
17. X. Chen and W. Thomas, Students who study science, technology, engineering, and mathematics (STEM) in postsecondary education, NCES 2009-161, U.S. Department of Education, National Center for Education Statistics, Washington, DC, 2009.
18. R. B. Freeman and E. Jin, Where do new US-trained science-engineering PhDs come from?, Paper presented at the meeting of the American Association for the Advancement of Science, 2003, https://www.ilr.cornell.edu/cheri/conferences/upload/2003may/chericonf2003_03.pdf.
19. E. T. Pascarella and P. T. Terenzini, *How College Affects Students: A Third Decade of Research,* Jossey-Bass, San Francisco, CA, 2005.
20. Carnegie Foundation for the Advancement of Teaching, Carnegie Classifications, http://classifications.carnegiefoundation.org, accessed 14 July 2012.
21. E. Seymour, The problem iceberg in science, mathematics, and engineering education: Student explanations for high attrition rates, *Journal of College Science Teaching,* **21**(4), 1992, pp. 230–238.
22. R. M. Marra, D. Shen, K. A. Rodgers and B. Bogue, Leaving engineering: A multi-year single institution study, Paper presented at the Annual Meeting of the American Educational Researcher's Association, San Diego, CA, 2009.
23. W. Tyson, R. Lee, K. M. Borman and M. A. Hanson, Science, technology, engineering, and mathematics (STEM) pathways: High school science and math coursework and postsecondary degree attainment, *Journal of Education for Students Placed at Risk,* **12**(3), 2007, pp. 243–270.
24. R. M. Felder and L. K. Silverman, Learning and teaching styles in engineering education, *Journal of Engineering Education,* **78**(7), 1988, pp. 674–681.
25. L. Fleming, K. Engerman and D. Williams, Why students leave engineering: The unexpected bond, *Proceedings of the 36th ASEE/IEEE Frontiers in Education Conference,* Chicago, IL, 2006.
26. A. C. Johnson, Unintended consequences: How science professors discourage women of color, *Science Education,* **91**, 2007, pp. 805–821.
27. N. C. Lagoudas, Women in engineering at the undergraduate level, Honors Fellow Thesis, Texas A&M University, 2009.
28. R. Marra, B. Bogue, D. Shen and K. Rodgers, Those that leave: Assessing why students leave engineering, *Proceedings of the 37th ASEE/IEEE Frontiers in Education Conference,* Honolulu, HI, 2007.
29. M. S. Sondgeroth and L. M. Stough, Factors influencing the persistence of ethnic minority students enrolled in a college engineering program. Paper presented at the meeting of the American Educational Research Association, San Francisco, CA, 1992.
30. A. C. Strenta, R. Elliot, R. Adair, M. Matier and J. Scott, Choosing and leaving science in highly selective institutions, *Research in Higher Education,* **35**(5), 1994, pp. 513–537.
31. D. C. Woolston, K. Shook and J. Wilson, Same problem, different solutions: Attempts at improving retention in engineering at a research vs. a teaching university, *Proceedings of the 25th ASEE/IEEE Frontiers in Education Conference,* Atlanta, GA, 1995.
32. S. Haag, N. Hubele, A. Garcia and K. McBeath, Engineering undergraduate attrition and contributing factors, *International Journal of Engineering Education,* **23**(5), 2007, pp. 929–940.
33. L. E. Bernold, J. E. Spurlin and C. M. Anson, Understanding our students: A longitudinal study of success and failure in engineering with implications for increased retention, *Journal of Engineering Education,* **96**(3), 2007, pp. 263–274.
34. A. Cabrera, C. Colbeck and P. Terenzini, Teaching for professional competence: Instructional practices that promote development of group problem solving and design skills, Paper presented at the meeting of the Association for the Study of Higher Education, Miami, 1998.
35. U. Gneezy, K. L. Leonard and J. A. List, Gender differences in competition: The role of socialization, University of Chicago, mimeo, 2006.
36. R. Stevens, K. O'Conner, L. Garrison, A. Jocuns and D. M. Amos, Becoming an engineer: Toward a three-dimensional view of engineering learning, *Journal of Engineering Education,* **9**(3), 2008, pp. 335–368.
37. C. Baillie and G. Fitzgerald, Motivation and attrition in engineering students, *European Journal of Engineering Education,* **25**(2), 2000, pp. 145–155.
38. R. M. Felder, G. N. Felder and E. J. Dietz, The effects of personality type on engineering student performance and attitudes, *Journal of Engineering Education,* **91**(1), 2002, pp. 3–17.
39. J. Grandy, Persistence in science of high-ability minority students: Results of a longitudinal study, *Journal of Higher Education,* **69**(6), 1998, pp. 589–620.
40. W. C. Leuwerke, S. Robbins, R. Sawyer and M. Hovland, Predicting engineering major status from mathematics achievement and interest congruence, *Journal of Career Assessment,* **12**, 2004, pp. 135–149.
41. B. F. French, J. C. Immekus and W. C. Oakes, An examination of indicators of engineering students' success and persistence, *Journal of Engineering Education,* **94**(4), 2005, 419–425.
42. K. G. Schaefers, D. L. Epperson and M. M. Nauta, Women's career development: Can theoretically derived variables predict persistence in engineering majors?, *Journal of Counseling Psychology,* **44**(2), 1997, pp. 173–183.
43. J. Levin and J. Wyckoff, Identification of student characteristics that predict persistence and success in an engineering college at the end of the sophomore year: Informing the practice of academic advising, Pennsylvania State University, 1990.
44. K. N. Rask and J. Tiefenthaler, The role of grade sensitivity in explaining the gender imbalance in undergraduate economics, *The Economics of Education Review,* **27**(6), 2008, pp. 676–687.
45. B. Ost, The role of peers and grades in determining major persistence in the sciences, *Economics of Education Review,* **29**(6), 2010, pp. 923–934.

46. R. M. Felder, G. N. Felder, M. Mauney, C. E. Hamrin and E. J. Dietz, A longitudinal study of engineering student performance and retention: Gender differences in student performance and attitudes, *Journal of Engineering Education,* **84**(2), 1995, 151–163.
47. A. E. Bell, S. J. Spencer, I. Iserman and C. E. R. Logel, Stereotype threat and women's performance in engineering. *Journal of Engineering Education,* **92**(4), 2003, pp. 307–312.
48. A. L. Griffith, Persistence of women and minorities in STEM field majors: Is it the school that matters?, *Economics of Education Review,* **29**, 2010, pp. 911–922.
49. S. Humphreys and R. Friedland, Retention in engineering: A study of freshman cohorts, University of California at Berkeley, Berkeley, CA, 1992.
50. M. W. Ohland, G. Zhang, B. Thorndyke and T. J. Anderson, Grade point average, changes of major, and majors selected by students leaving engineering, *Proceedings of the 34th ASEE/IEEE Frontiers in Education Conference,* Savannah, GA, 2004.
51. B. Brigeman and C. Lewis, The relationship of essay and multiple-choice scores with grades in college courses, *Journal of Educational Measurement,* **31**, 1994, pp. 37–50.
52. R. W. Lent, S. D. Brown, J. Schmidt, B. Brenner and D. Treistman, Relation of contextual supports and barriers to choice behavior in engineering majors: Test of alternative social cognitive models, *Journal of Counseling Psychology,* **50**(4), 2003, pp. 458–465.
53. C. M. Vogt, Faculty as a critical juncture in student retention and performance in engineering programs, *Journal of Engineering Education,* **97**(1), 2008, pp. 27–36.
54. G. E. DeBoer, Factors related to the decision of men and women to continue taking science courses in college, *Journal of Research in Science Teaching,* **21**(3), 1984, pp. 325–329.
55. M. M. Nauta, D. L. Epperson and K. M. Waggoner, Perceived causes of success and failure: Are women's attributions related to persistence in engineering majors?, *Journal of Research in Science Teaching,* **36**(6), 1999, pp. 663–676.
56. C. Moller-Wong and A. Eide, An engineering student retention study, *Journal of Engineering Education,* **86**(1), 1997, pp. 7–15.
57. W. Tyson, Modeling engineering degree attainment using high school and college coursetaking and achievement, *Journal of Engineering Education,* **100**(4), 2011, 760–777.
58. G. Zhang, T. J. Anderson, M. W. Ohland, R. Carter and B. Thorndyke, Identifying factors influencing engineering student graduation and retention: A longitudinal and cross institutional study, *Journal of Engineering Education,* **93**(4), 2004, pp. 313–320.
59. M. W. Ohland, C. E. Brawner, M. M. Camacho, R. A. Layton, R. A. Long, S. M. Lord and M. H. Wasburn, Race, gender, and measures of success in engineering education, *Journal of Engineering Education,* **100**(2), 2011, pp. 225–252.
60. J. Good, G. Halpin and G. Halpin, Retaining black students in engineering: Do minority programs have a longitudinal impact? *Journal of College Student Retention,* **3**(4), 2002, pp. 351–364.
61. M. S. Hyde and J. Gess-Newsome, Adjusting educational practice to increase female persistence in the sciences, *Journal of College Student Retention,* **1**(4), 1999, pp. 335–355.
62. A. P. Carnevale, J. Strohl and M. Melton, What's it worth? The economic value of college majors, Georgetown University Center on Education and the Workforce, Washington, DC, 2011.
63. S. R. Porter and R. L. Swing, Understanding how first year seminars affect persistence, *Research in Higher Education,* **47**(1), 2006, pp. 89–109.
64. R. M. Felder, G. N. Felder and E. J. Dietz, A longitudinal study of engineering student performance and retention: Comparisons with traditionally taught students, *Journal of Engineering Education,* **87**(4), 1998, pp. 469–480.
65. D. W. Knight, L. E. Carlson and J. Sullivan, Improving engineering student retention through hands-on, team based, first-year design projects, *Proceedings of the International Conference on Research in Engineering Education*, Honolulu, HI, 2007.
66. M. Prince, Does active learning work?: A review of the research, *Journal of Engineering Education,* **93**(3), 2004, pp. 223–231.
67. L. Springer, M. Stanne and S. Donovan, Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis, *Review of Educational Research,* **69**(1), 1999, pp. 21–51.
68. P. Terenzini, A. Cabrera, C. Colbeck, S. Bjorkland and J. Parente, Racial and ethnic diversity in the classroom: Does it promote student learning?, *Journal of Higher Education,* **72**(5), 2001, 509–531.
69. J. Berson and W. Younkin, Doing well by doing good: A study of the effects of a service-learning experience on student success, Paper presented at the meeting of the Association for the Study of Higher Education, Miami, 1998.
70. G. Markus, J. Howard and D. King, Integrating community service and classroom instruction enhances learning: Results from an experiment, *Experimental Education and Policy Analysis,* **15**, 1993, pp. 410–419.
71. S. E. Brownell, M. J. Kloser, T. Fukami and R. Shavelson, Undergraduate biology lab courses: Comparing the impact of traditionally based "cookbook" and authentic research-based courses on student lab experiences, *Journal of College Science Teaching,* **41**(4), 2012, pp. 36–45.
72. M. Hoit and M. Ohland, Impact of a discipline-based introduction to engineering course on improving retention, *Journal of Engineering Education,* **87**(1), 1998, pp. 79–85.
73. N. Al-Holou, N. A. Gilgutay, C. Corleto, J. T. Demel, R. Felder, K. Frair, J. E. Froyd, M. Hoit, J. Morgan and D. L. Wells, First year integrated curricula: design alternatives and examples, *Journal of Engineering Education,* **88**(4), 1999, pp. 435–448.
74. E. Newton and L. Wells-Glover, Mentors for undergraduates in technical disciplines: A collaborative effort by faculty, student development professionals, and alumni to improve undergraduate student retention and success in technical programs, *Journal of College Student Retention,* **1**(4), 1999, pp. 311–321.
75. B. Bloom, The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring, *Educational Researcher,* **13**(6), 1984, pp. 4–16.
76. D. Street, S. Brown, C. Schramm and K. Gillespie, The impact of an in-class peer tutoring program on student social capital, *Proceedings of the 39th ASEE/IEEE Frontiers in Education Conference,* San Antonio, TX, 2009.
77. B. A. Nagda, S. R. Gregerman, J. Jonides, W. Hippel and J. S. Learner, Undergraduate student–faculty research partnerships affect student retention, *Review of Higher Education,* **22**(1), 1998, pp. 55–72.
78. T. J. Webster, and K. C. Dee, Supplemental instruction integrated into an introductory engineering course, *Journal of Engineering Education,* **87**(4), 1998, pp. 377–383.
79. E. Grant-Vallone, K. Reid, C. Umali and E. Pohlert, An analysis of the effects of self-esteem, social support, and participation in student support services on students' adjustment and commitment to college, *Journal of College Student Retention,* **5**(3), 2004, pp. 255–274.
80. R. Perry and K. Penner, Enhancing academic achievement in college students through attributional retraining, *Journal of Educational Psychology,* **82**, 1990, pp. 262–271.
81. M. L. Smith and G. V. Glass, Meta-analysis of psychotherapy outcome studies, *American Psychologist,* **32**(9), 1977, pp. 752–760.

Brandi N. Geisinger is a Program Coordinator specializing in research and evaluation of educational programs at the Research Institute for Studies in Education at Iowa State University. She earned her B.S. in Psychology, graduating Magna Cum Laude from Iowa State University. She earned her M.S. in Sociology at Iowa State University where she focused on gender and social inequality issues, writing a thesis entitled *Critical Feminist Theory, Rape, and Hooking Up*. Her current research focuses on the assessment and evaluation of a diverse array of topics including online courses, summer research internships, service learning projects, and faculty's broader impacts activities. Geisinger is passionate about issues related to gender and social inequality; she intends to pursue research related to these topics as she continues her education.

D. Raj Raman is Professor and Associate Chair for Teaching in the Agricultural and Biosystems Engineering (ABE) Department at Iowa State University, and a licensed Professional Engineer. He earned his B.S. in Electrical Engineering from the Rochester Institute of Technology and his Ph.D. in Agricultural and Biological Engineering from Cornell University, and then joined the faculty of the University of Tennessee for twelve years, during which time he developed or co-developed and taught or co-taught half a dozen new courses, ranging from senior design for small groups of students to freshmen engineering programming with 500+ students, while conducting research on the biological treatment of organic wastes. He has received departmental, college, and national teaching honors including the Farrall Young Educator Award given by the American Society of Agricultural Engineers. At Iowa State University, Raman served as the first Associate Director of Education for the Office of Biorenewables Programs, and as the Director of Graduate Education for the Biorenewable Resources and Technology program. He chairs the ABE Engineering Curriculum Committee and in that role oversaw the 2012 ABET accreditation visit for both the Agricultural Engineering and Biological Systems Engineering degree programs, the latter of which he led the development of from 2006 to 2008, and which now enrolls over 80 students. Raman also runs multiple summer research internship programs through his roles as University Education Director for the NSF Engineering Research Center for Biorenewable Chemicals (CBiRC), and Education Co-Director for the USDA-funded CenUSA project. The CenUSA project aims to develop biorenewable liquid fuels derived from non-food crops grown on marginal lands. In his role as Pyrone Testbed Champion for CBiRC, Raman and his students are developing early-stage techno-economic models of bioprocessing systems.